Calorimeter R&D for COMET

Akira SATO
Osaka University
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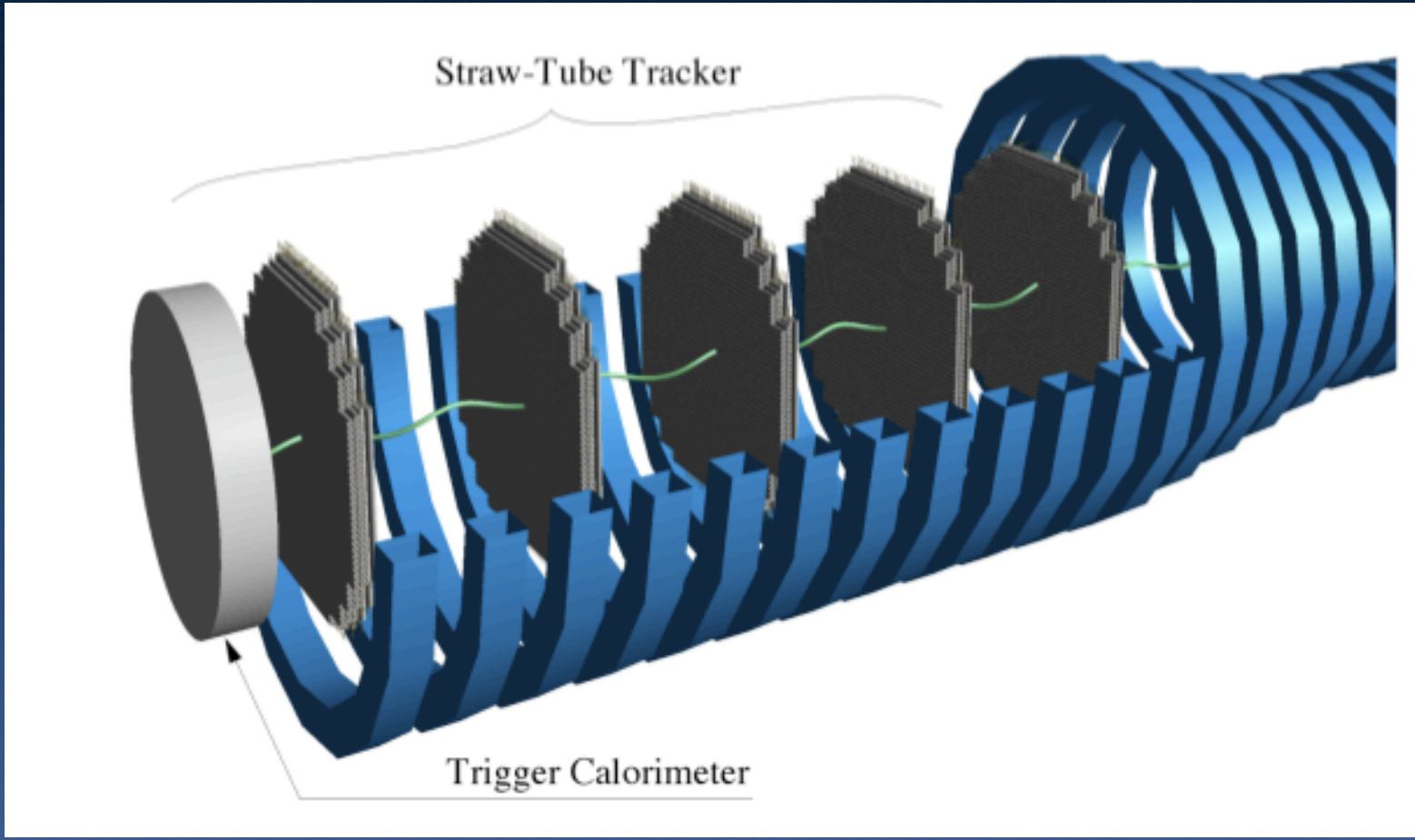

Straw-Tube Tracker
Trigger Calorimeter

Calorimeter

- Crystal array at the end of solenoid channel (size Φ1m, $11X_0$)
- Requirements
  - Energy resolution : σ < 5% at 100 MeV
  - Trigger Rate : < 5-10 kHz
  - Spacial resolution : < 1.5 cm
  - Fast response : < 100ns
  - Operate in a vacuum with 1 T magnetic field
- Candidates of crystal
  - GSO(Ce) : enough light yield and fast response, but relatively expensive. difficult to get lager crystals.
  - LYSO: enough light yield and fast response, but relatively expensive.
  - PWO : less expensive, faster response. Large crystal is available. But, poor light yield. Needs cooling to increase light yield.
- Candidates of photon detector
  - MPPC : high gain. Needs more R&D.
  - APD : established. low gain.

R&D items

- Crystal
  - check properties
- MC simulation
  - including photon tracking in the crystal and light guide
  - compare results of MC with that of from beam tests
  - understand energy resolution
  - optimize calorimeter
- Photon detector
  - PMT / APD / MPPC
- Readout electronics

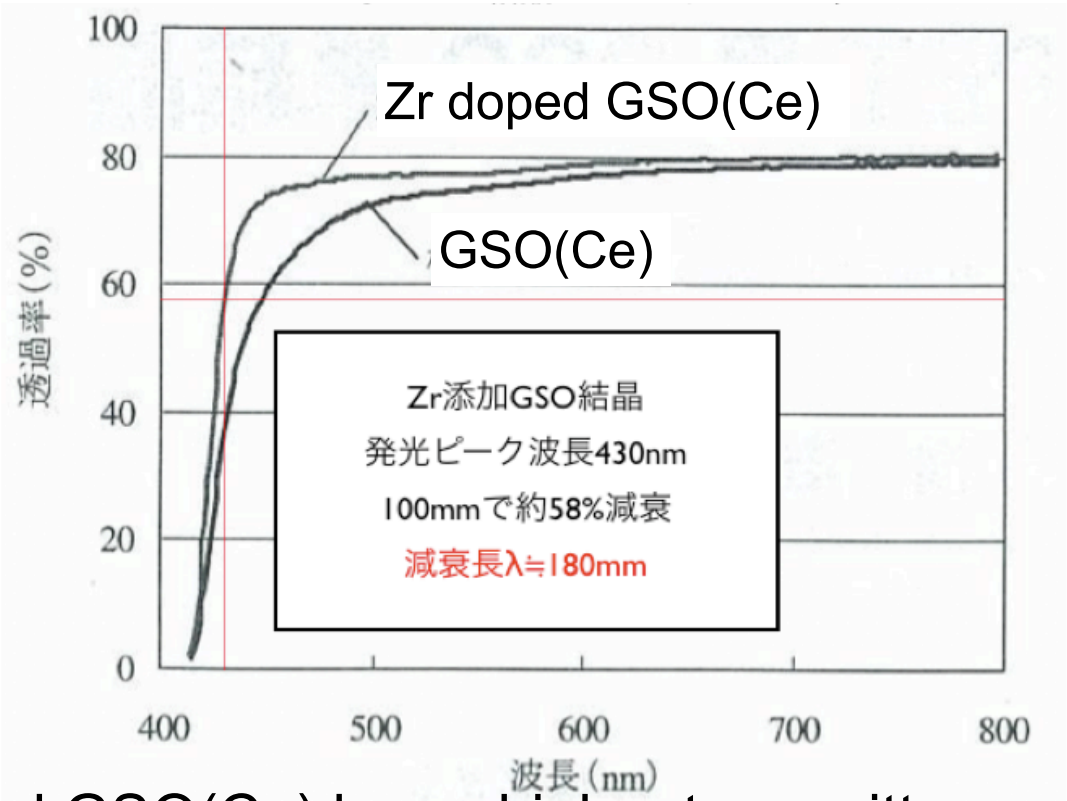
Crystals

Table 28.4: Properties of several inorganic crystal scintillators. Most of the notation is defined in Sec. 6 of this *Review*.

Parameter: ρ	MP	X_0^*	R_M^*	dE/dx	λ_I^*	τ_{decay}	λ_{max}	$n^\natural$	Relative output†	Hygro-scopic?	$d(\text{LY})/dT$
Units: g/cm^3	°C	cm	cm	MeV/cm	cm	ns	nm				%/°C‡
NaI(Tl) 3.67	651	2.59	4.13	4.8	42.9	230	410	1.85	100	yes	−0.2
BGO 7.13	1050	1.12	2.23	9.0	22.8	300	480	2.15	21	no	−0.9
BaF_2 4.89	1280	2.03	3.10	6.6	30.7	630^s	300^s	1.50	36^s	no	-1.3^s
						0.9^f	220^f		3.4^f		$\sim 0^f$
CsI(Tl) 4.51	621	1.86	3.57	5.6	39.3	1300	560	1.79	165	slight	0.3
CsI(pure) 4.51	621	1.86	3.57	5.6	39.3	35^s	420^s	1.95	3.6^s	slight	−1.3
						6^f	310^f		1.1^f		
$PbWO_4$ 8.3	1123	0.89	2.00	10.2	20.7	30^s	425^s	2.20	0.083^s	no	−2.7
						10^f	420^f		0.29^f		
LSO(Ce) 7.40	2050	1.14	2.07	9.6	20.9	40	420	1.82	83	no	−0.2
GSO(Ce) 6.71	1950	1.38	2.23	8.9	22.2	600^s	430	1.85	3^s	no	−0.1
						56^f			30^f		

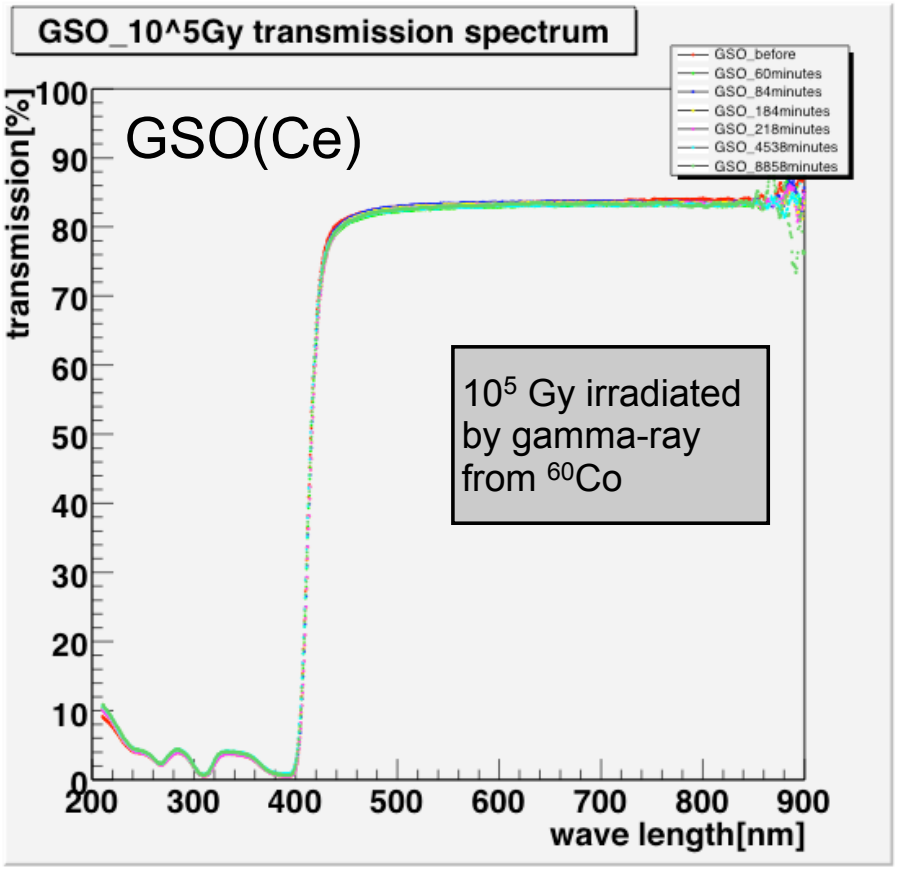
We have GSO(Ce) and LYSO (from JINR) now. PWO would be delivered.
Properties of GSO(Ce) were studied at Osaka U.

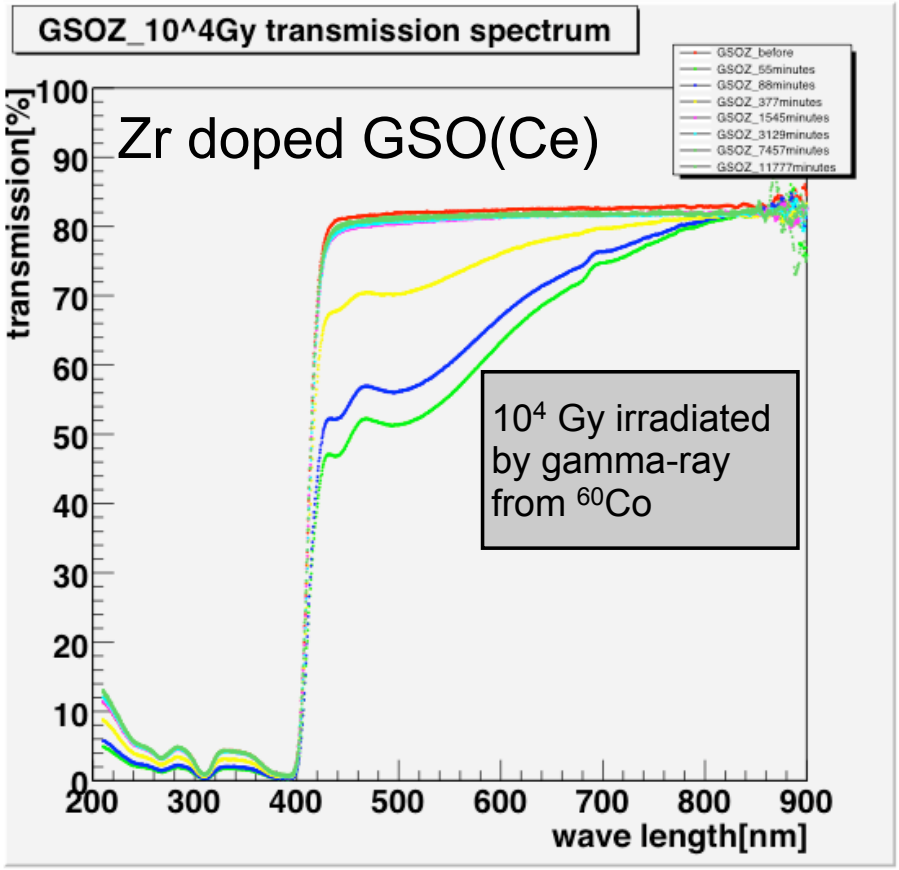
Zr doped GSO(Ce) by Hitachi material Co.



Zr doped GSO(Ce) has a higher transmittance.
But there was no data about radiation hardness for that.
We measured it.

Radiation hardness of GSO(Ce) and Zr-GSO(Ce)

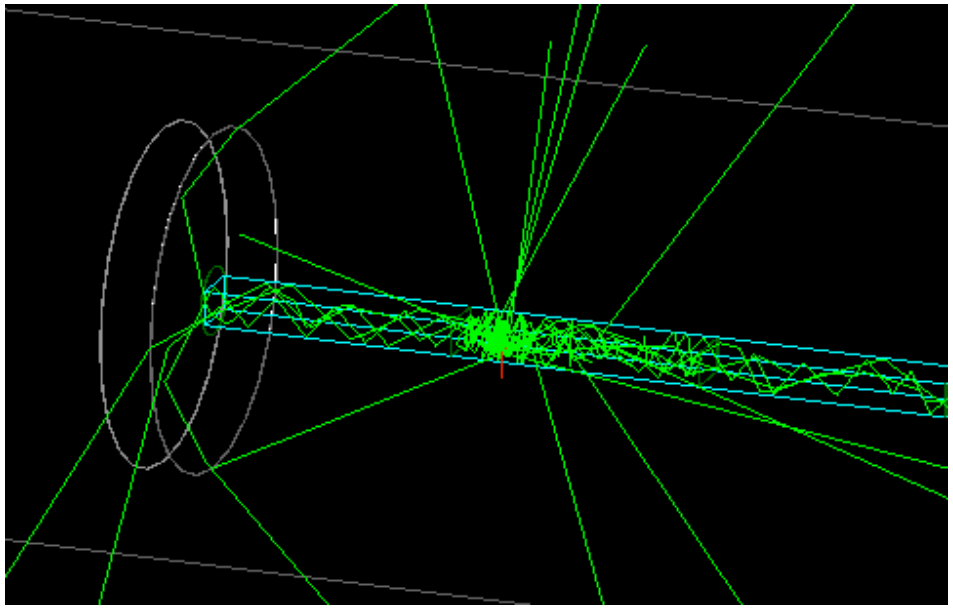


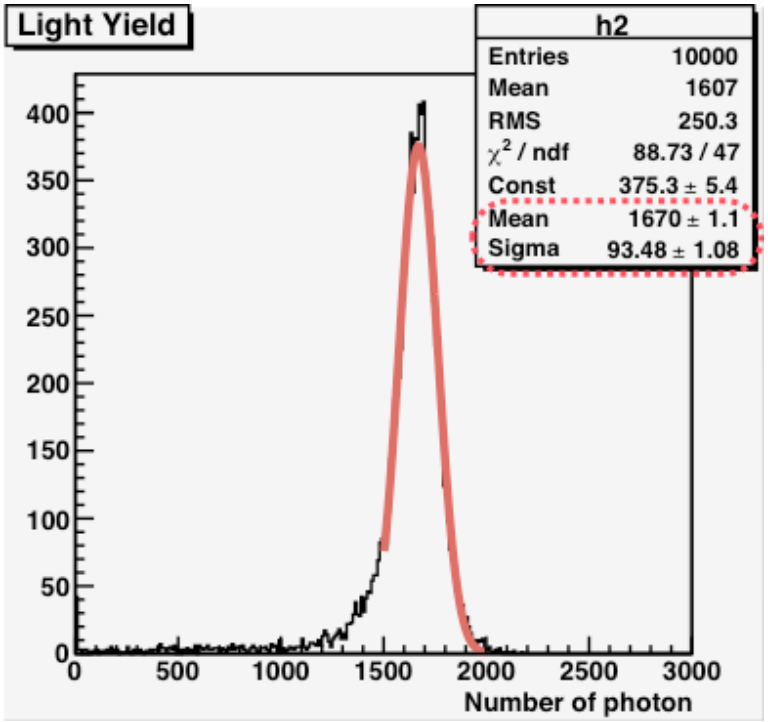


- GSO(Ce) has high radiation hardness as expected.
- Zr doped GSO(Ce), which has higher light yield, has less hardness.

Simulation study

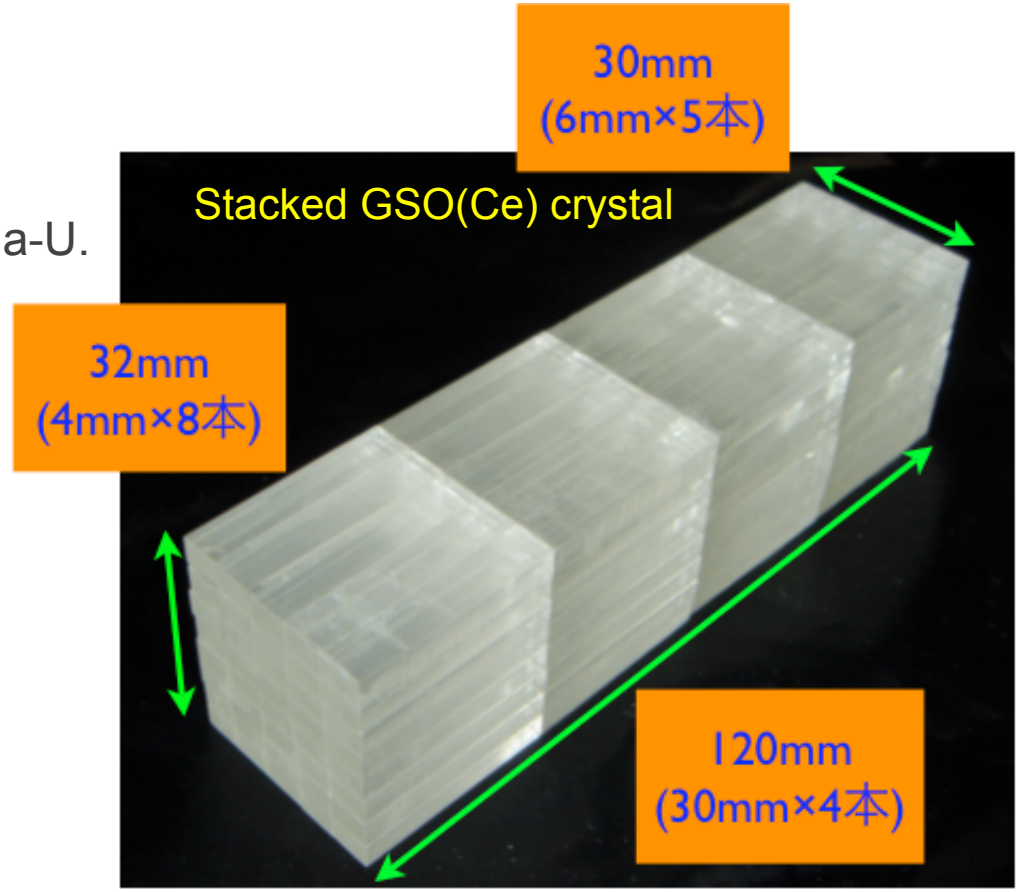
- Ray tracing in crystals using geant4 with Optical Photon Processes
  - Optimization of crystals and photon detectors.
  - Estimate the energy resolution and its components.



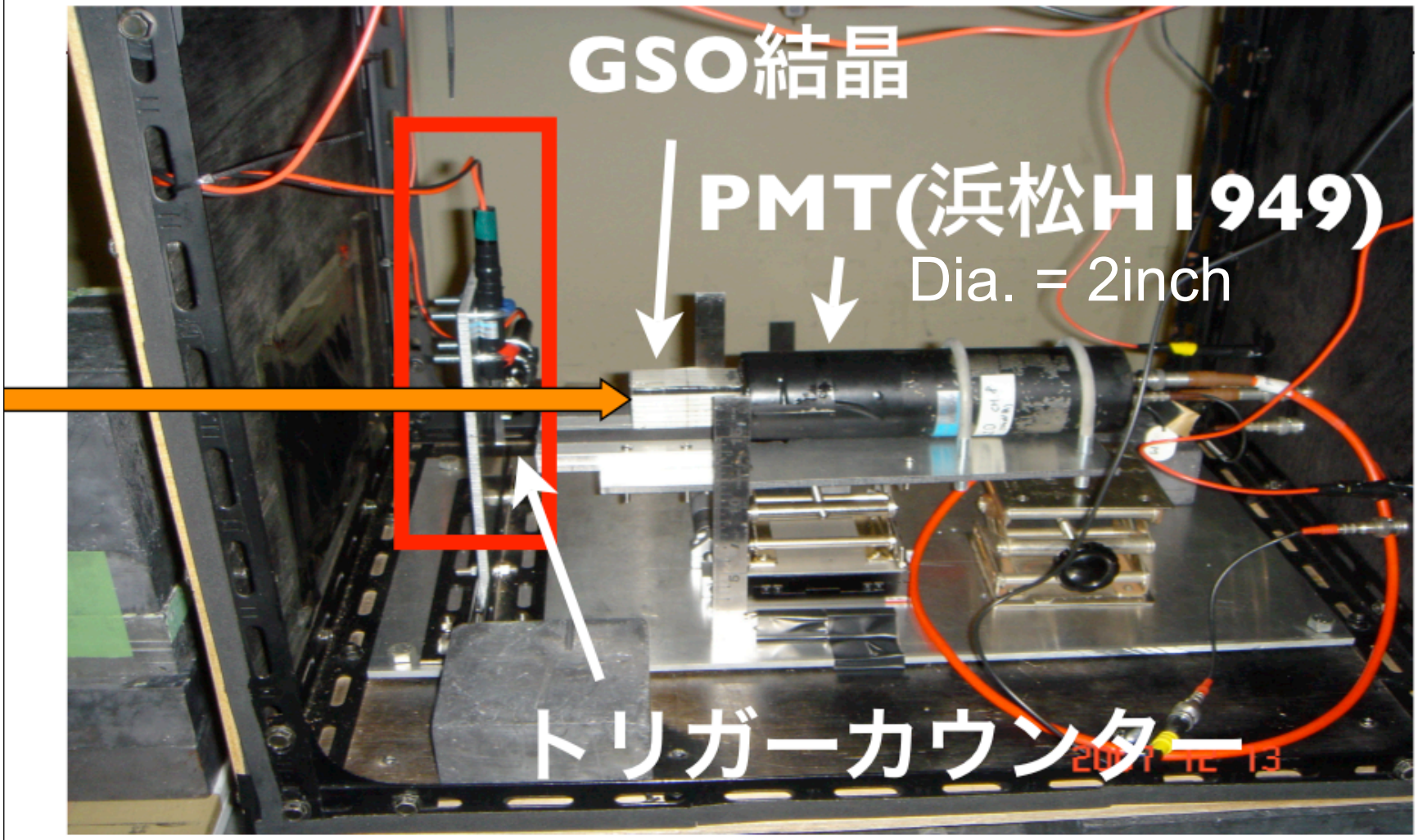


Beam test with GSO(Ce) crystal : Dec. 2007

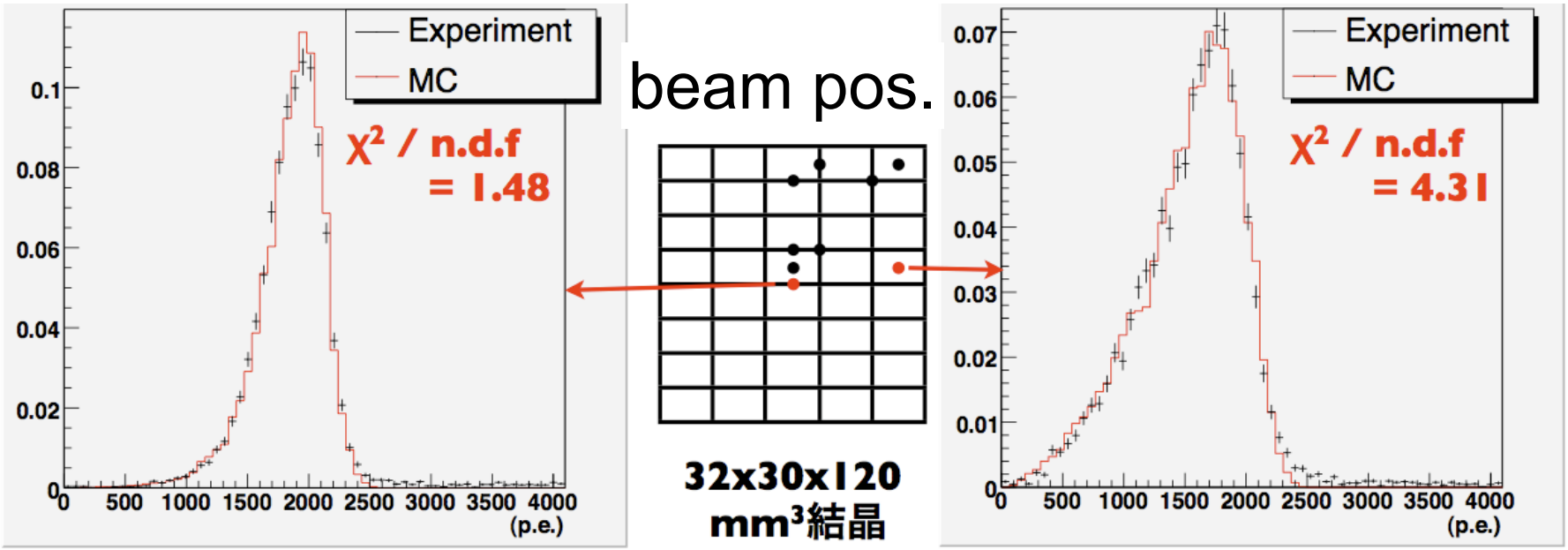
- Purpose
  - check the MC results
- GSO(Ce) with PMT
  - 150 MeV e^- beam
  - from REFER, Hiroshima-U.



Beam test with GSO(Ce) crystal : Dec. 2007



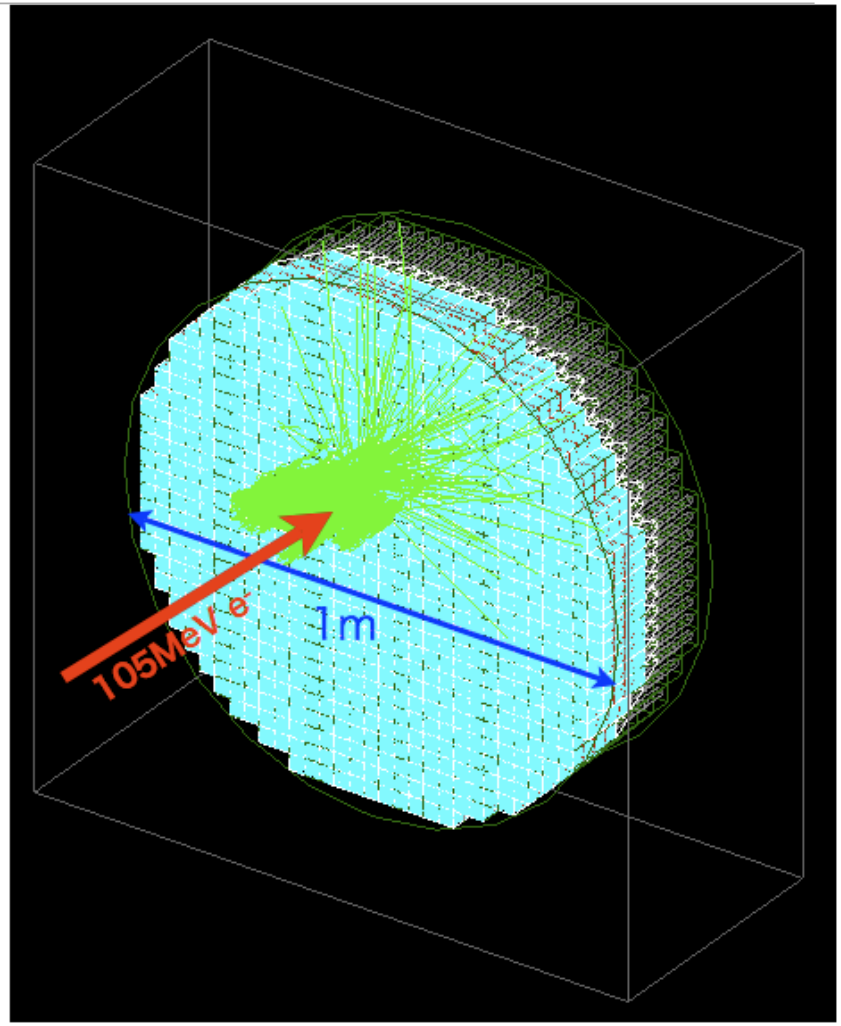
Beam test with GSO(Ce) crystal : Dec. 2007



Good agreements with the simulation results

Estimation of σ_E with the MC

- After optical parameters in the MC tuned to fit the result of the beamtest result.
- Energy resolution at 105 MeV electrons was estimated for COMET calorimeter using the MC code.
- Crystals
  - stacked GSO
  - bulk GSO
  - bulk PWO
  - bulk LYSO



Energy reso. with large photon detectors by MC

- Photon det. covers full size of crystal. (ultimate case!)

	stacked GSO	bulk GSO	bulk PWO
$\sigma_E/E(\%)$	5.32 ± 0.08	4.02 ± 0.04	2.68 ± 0.03

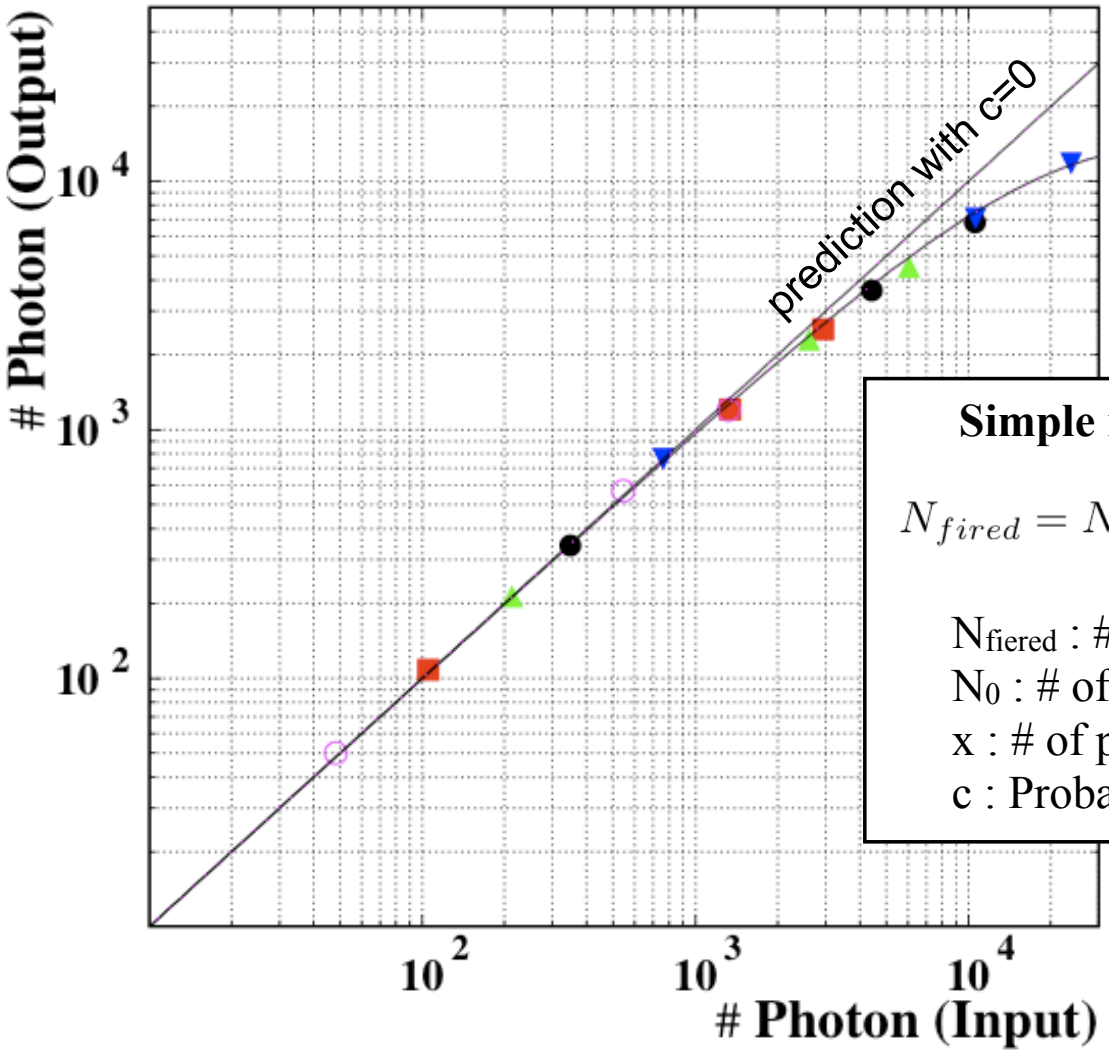
One graduate student of Osaka Univ. works on this study for his Master thesis.
We will get a lot of result of the MC:
* Dependency of energy resolution on
Crystal, P.D., Light guide, and their size

Candidates of Photon Detector

	PMT	APD	MPPC
Gain	~10^6	~10^2	10^5~10^6
Photon Detection Efficiency	0.1~0.2	0.7~0.8	0.2-0.5
Response	~40ps		~110ps
Bias voltage	~2000V	300~500V	30~75V
Size	large	25~100mm^2	1~9mm^2
B field	Sensitive	No influence	No influence
Cost	high	700USD for 100mm^2	250USD for 9mm^2
Dynamic range	Good		poor linearity
Stability	Good		
Noise	Quiet		Noisy(small p.h.)

We study the MPPS for COMET calorimeter with support from KEK photon detector group from 2008.

Linearity : MPPC 3x3 mm^2 (25um pixel) HPK

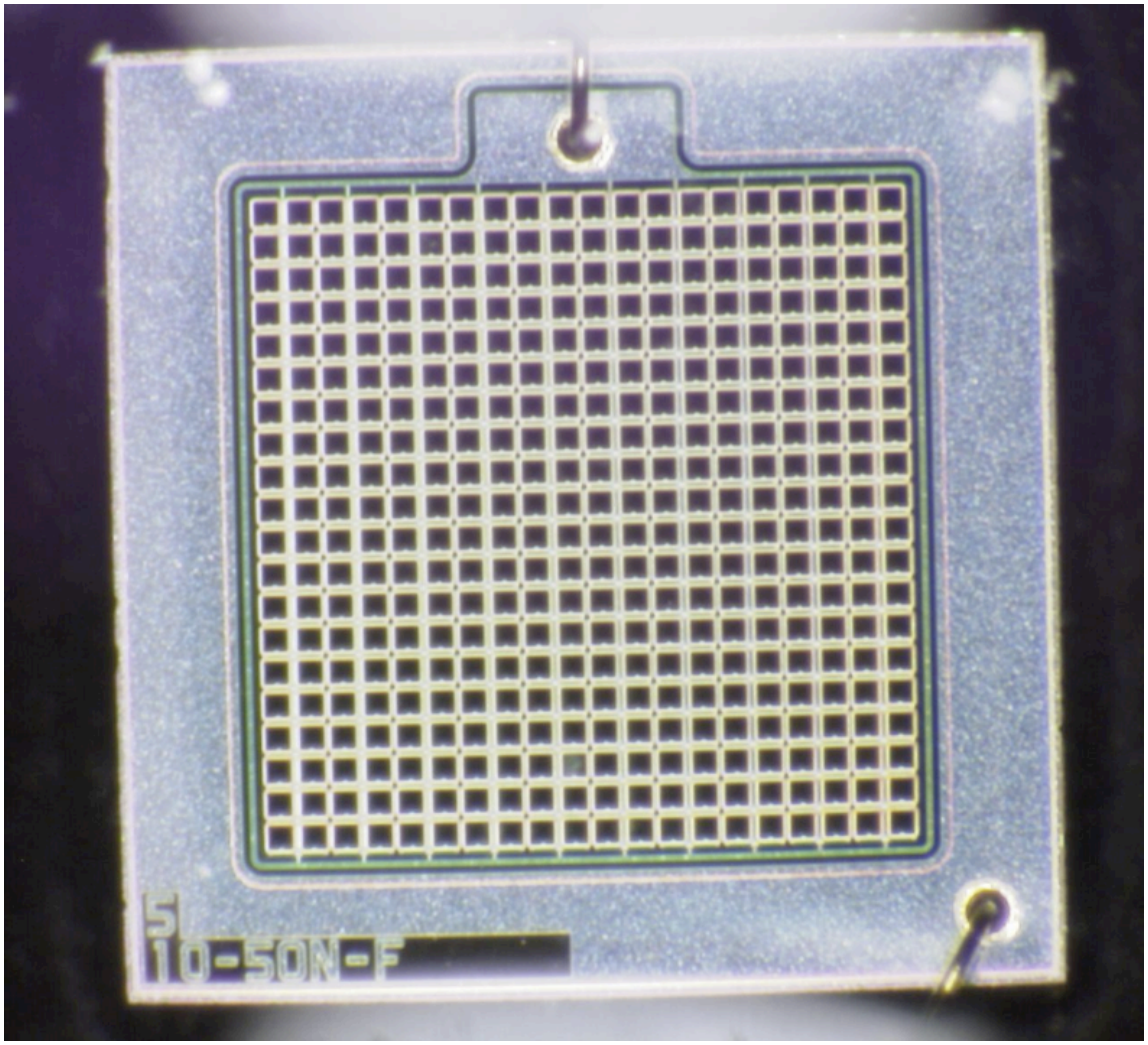


Simple model of MPPC linearity

$$N_{fired} = N_0 \times \left(1 - \exp\left(-\frac{x(1+c)}{N_0}\right)\right)$$

N_{fiered} : # of pixels fired a signal
N_0 : # of pixel on the MPPC
x : # of p.e. inputed
c : Probability cross talk/after pulse

MPPC 1x1 mm^2 (400pixels) HPK



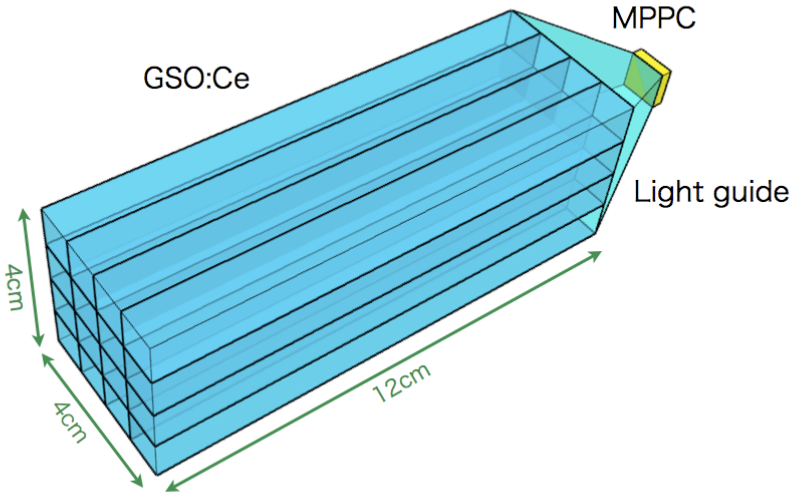
2nd Beam Test
26 Nov. - 9 Dec., 2008

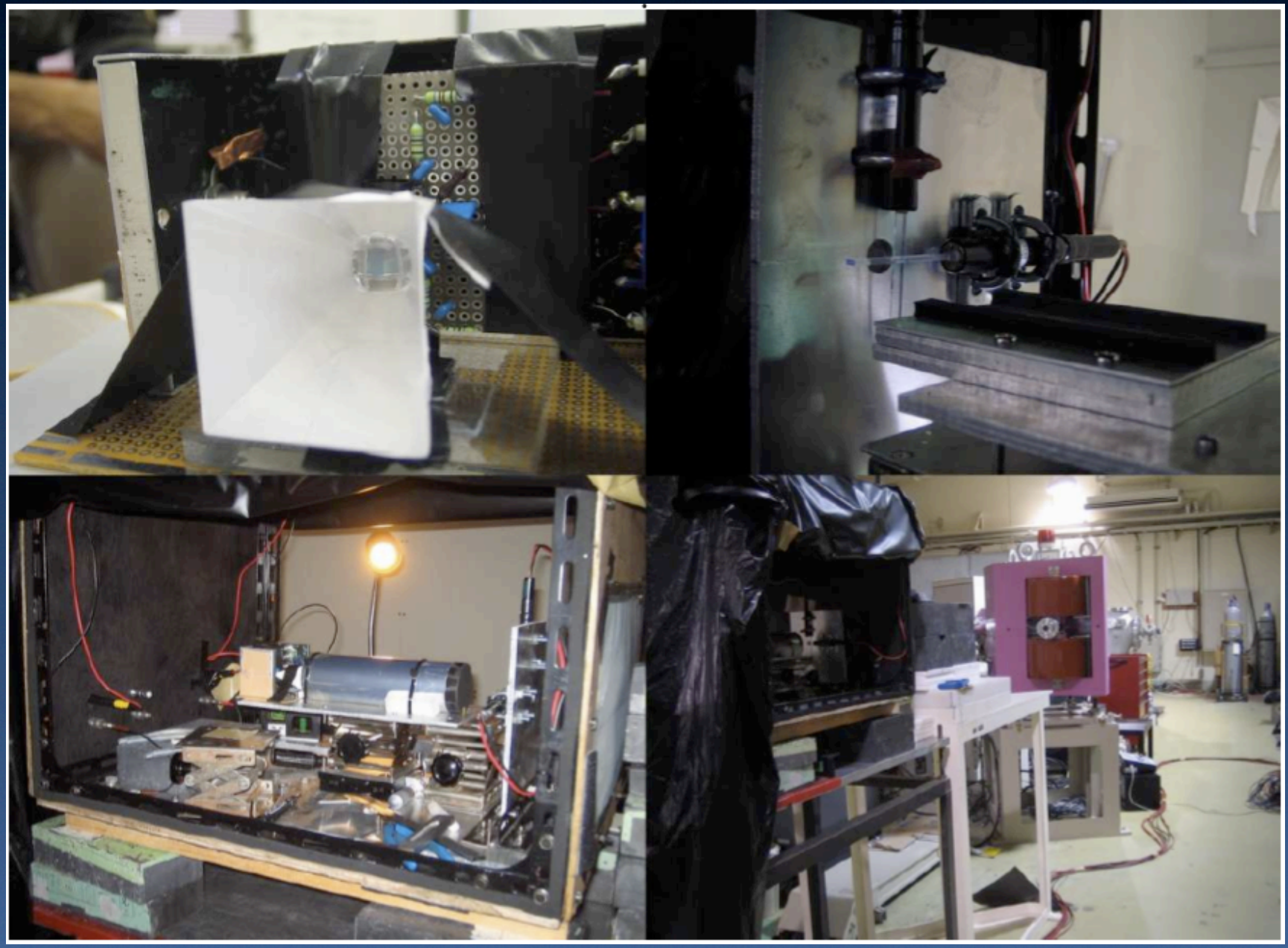
Preliminary results

*Study of light guide effect

* APD readout

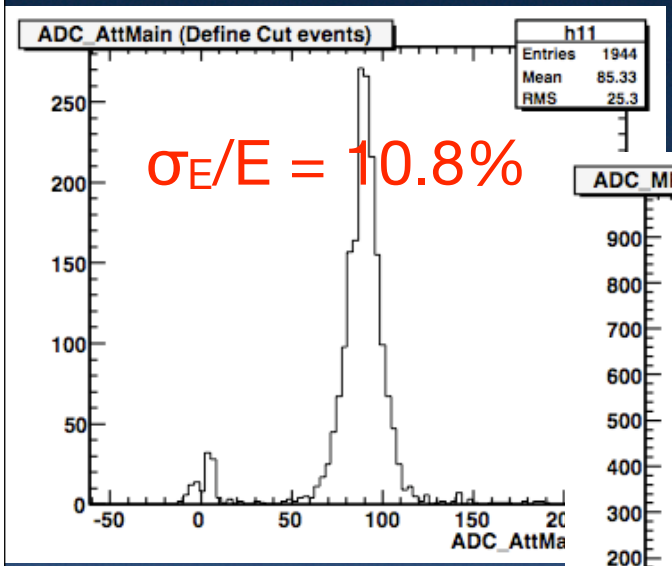
* LYSO with
  PMT /
  MPPC 1 mm^2 /
  MPPC 9 mm^2



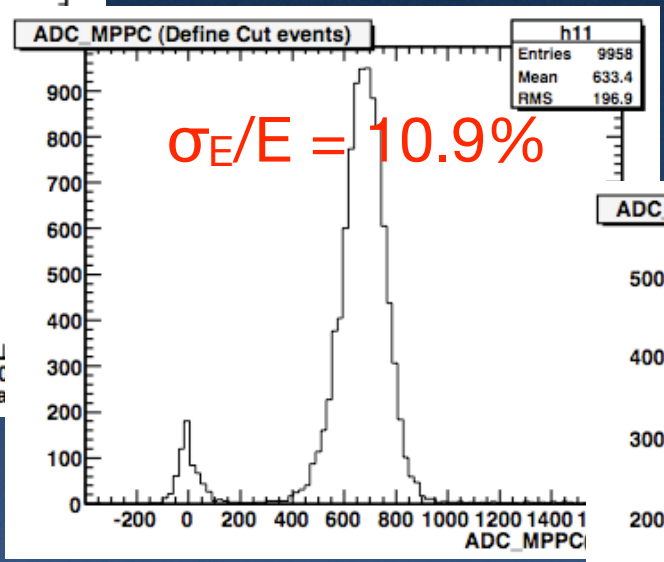


Preliminary results

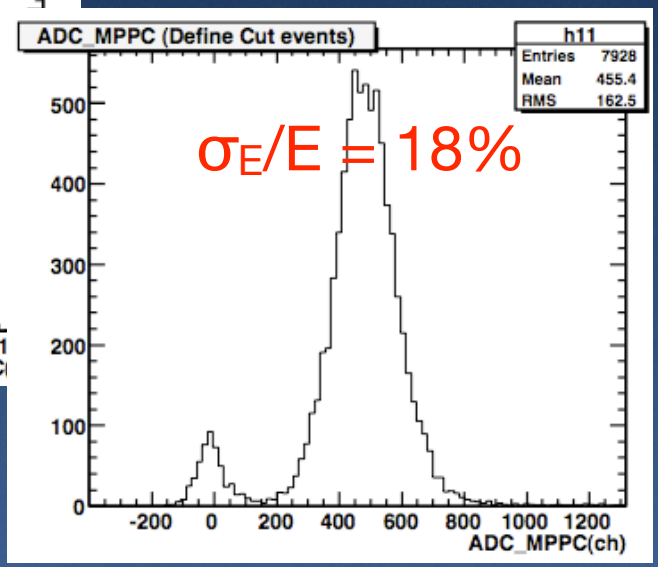
LYSO (6cmΦ x 20cm) without the light guide



LYSO with PMT

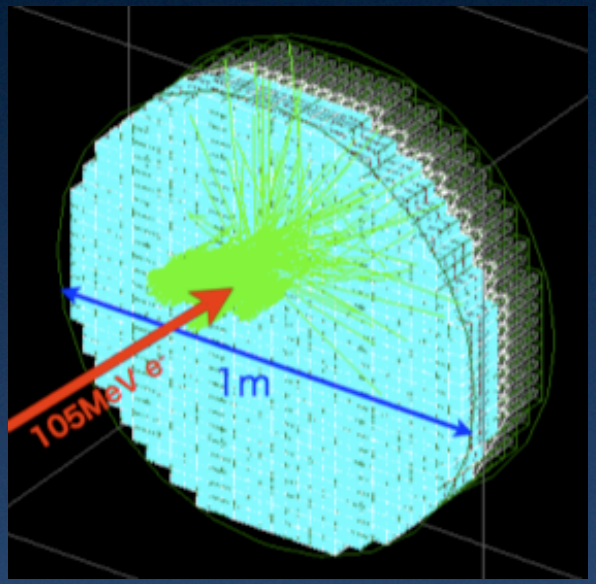


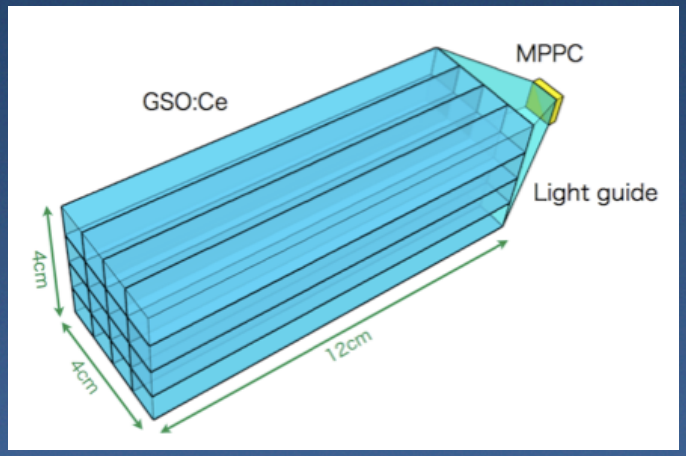
LYSO with MPPC 9 mm^2



LYSO with MPPC 1 mm^2

MC to optimize the system





other candidates

Small MPPCs connected to a segment of the crystal directly

Small MPPCs connected to a segment of the crystal with LG.

Summary

- Calorimeter R&D is one of the ongoing studies of COMET.
- Need to select and optimize
  - Crystal : GSO, LYSO, PWO
  - Photon Det. : MPPC, APD
- R&Ds
  - Crystal property measurement : GSO done, LYSO soon
  - Beam test with 150MeV electrons : carried out twice
  - MC with geant4 : developed -> results by the end of March
  - MPPC/APD readout : underway 2008-2009
  - My hope 2009- (depends on the budget)
    - Beamtest with PWO/LYSO/GSO and MPPC/APD
      - prototypes of optimized geom.
    - develop readout and frontend electronics

Resolution and Trigger Rate

カロリメータの種類	運動量分解能 σ(MeV/c)	DIO による単位時間トリガー数 (Hz)
積層型 Zr-GSO(Ce)	5.72±0.08	33 ± 1
Zr-GSO(Ce)	4.02±0.04	17 ± 1
PWO	2.81±0.03	2.1 ± 0.1